NOAA SECTORAL APPLICATIONS RESEARCH PROGRAM (SARP)
PROJECT ANNUAL REPORT (DRAFT)

PROJECT TITLE

Climate and Management of the Colorado River

INVESTIGATORS *(Research team and full contact information)*

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PROJECT YEARS: 2005 TO PRESENT

TIME PERIOD ADDRESSED BY REPORT: 7/1/07 to 6/30/08

I. PRELIMINARY MATERIALS

A Project Abstract (Limit to one page)

Ongoing drought (2000 to 2008) in the Colorado River basin has significantly depleted storage in Lakes Powell and Mead, raising the prospect that water deliveries promised to basin states and individual water users may soon be significantly curtailed. This event would be unprecedented and would have wide ranging consequences, and until the recent multi-year drought, had not been seriously considered by the research or management community with one notable exception: the *Severe Sustained Drought in the Southwestern United States* (hereafter the "SSD study") (Gregg and Getches, 1991; Young, 1994). Completed a decade ago, the SSD study was widely recognized for its forward-looking conclusions and for its methodological approach blending research in paleoclimatology, water management, economics, and legal and policy analysis. However, the research was not immediately influential in prompting institutional

reforms; it has taken the drought crisis to spark action. Revisiting the SSD study in light of the ongoing drought (and drought response) is useful for several reasons, including (a) improving our understanding of how regional water supply vulnerability has evolved in the region, and (b) exploring how future climate-oriented planning scenarios can be better integrated with the needs and opportunities available to decision-makers.

B Objectives of Research Project

The objectives of this project are generally two-fold: first, to inform ongoing and future management efforts in the basin by providing insights into the role of climate variability (and climate change) in shaping water supply vulnerability on the Colorado River; and second, to inform research and technical support activities, including NOAA climate services, regarding ways to better structure and link climate research/data with the needs of water policy and management.

C Approach (including methodological framework, models used, theory developed and tested, project monitoring and evaluation criteria) include a description of the key beneficiaries of the anticipated findings of this project (e.g., decision makers in a particular sector/level of government, researchers, private sector, science and resource management agencies) *(Limit to one page)*

Research has been conducted through a review of literature and statistics, and more importantly, through ongoing interactions with key water managers and policy-makers in the Colorado River Basin. This project does not rely upon extensive new modeling efforts or the development of new databases, but rather is limited to a largely qualitative analysis of SSD modeling results and current drought impacts. It is important to appreciate that the current drought crisis has prompted a variety of research and policy initiatives which this project is now integrated with. Key processes include a recently-completed (December 2007) federal EIS process considering new drought-coping plans, a National Research Council study (completed in February 2007) reviewing long-term flows on the river, and ongoing work of the NOAA-RISA Western Water Assessment. Key collaborators and beneficiaries from the project are federal agencies (particularly the US Bureau of Reclamation and NOAA), state water agencies (in Colorado, Wyoming, New Mexico, Utah, Arizona, Nevada and California), and countless regional urban and municipal water providers.

Key to understanding the difference between SSD modeled and actual drought impacts is an appreciation that the river system has changed in the past 15 years in several ways: namely, the (a) the sociopolitical, legal and demographic context of the region has significantly changed; (b) new water projects and management regimes have been implemented; and (c) there is currently a much more advanced understanding of the climate system—past, present, and future—including the potential impacts of climate change and shorter drought periods on water management that were not included in the original SSD investigation. We are revisiting the general assumptions, themes, and findings of the SSD study in light of changing circumstances and current drought

impacts, identifying and explaining those areas where the traditional characterization of vulnerability (as described in SSD research) is no longer accurate.

D Description of any matching funds/activities used in this project *(Limit to one paragraph)*

The scope of work conducted under this study has been significantly expanded since its inception, as the flurry of drought-inspired policy and management discussions have provided both an opportunity and necessity for greater stakeholder engagements. This has only been possible by linking project activities with those of the Western Water Assessment (NOAA-RISA), and to a lesser extent, the NIDIS program (now headed by project co-PI Pulwarty). (Also of note is the current affiliation of a project member, Connie Woodhouse, in the CLIMAS program, another RISA.) Involvement of the Western Water Assessment has leveraged both intellectual and budgetary resources, and has allowed us to pursue a more diversified suite of projects (as outlined below).

II. ACCOMPLISHMENTS

A. Brief discussion of project timeline and tasks accomplished. Include a discussion of data collected, models developed or augmented, fieldwork undertaken, or analysis and/or evaluation undertaken, workshops held, training or other capacity building activities implemented. *(This can be submitted in bullet form – limit to two pages)*

In order to learn from the unfolding drought (and drought response) in the region, and to capitalize upon the many related studies and policy processes, the timeline of this project was extended twice, and almost all project activities were coordinated in some way with other efforts, particularly those of the Western Water Assessment. Because of this, it is difficult to provide a clear attribution of products to exclusively this project. The list of accomplishments provided below in item II.C., therefore, includes products and presentations that are associated, *in whole or in part*, with this study.

Research completed to date includes a full review of SSD project materials (and relevant supporting literatures), participation of at least one project member in virtually all major conferences in the region (including, for example, the annual meetings of the Colorado River Water Users Association), participation of project members in recent policy and research processes (including, for example, the National Academies report on Colorado River flows), outreach to original SSD researchers and current water managers to solicit input in the analysis of impacts (see item II.B for major themes and conclusions), and the hosting of conferences and workshops to assist in information gathering, outreach and dissemination of ideas/findings. Three conference/workshop efforts are particularly noteworthy:

* In conjunction with the Natural Resources Law Center and the Western Water Assessment, project members designed and hosted the 3-day event: "Hard Times on the Colorado River: Drought, Growth and the Future of the Compact." (June 2005) [led by Kenney]

* In conjunction with the Western Water Assessment (and more recently with CLIMAS), several collaborative activities and workshops have been held with Colorado water managers to explain the science behind tree-ring reconstructions and to explore ways to use reconstructions in water resource planning and management (e,g,, workshops in Boulder, May 8-9, May 17, 2006; see http://wwa.colorado.edu/resources/paleo/; and in Albuquerque New Mexico, November 2, 2007; *see* http://wwa.colorado.edu/resources/paleo/albuquerque_workshop.html). (More generally, see http://wwa.colorado.edu/resources/paleo/lees/) [led by Woodhouse]

* In conjunction with several partners (The Nature Conservancy, Trout Unlimited, Environmental Defense, the Western Water Assessment, Western Resource Advocates, and the U.S. Bureau of Reclamation), the project was the springboard for a public event held on March 21, 2008, entitled: "Securing Environmental Flows on the Colorado River in an Era of Climate Change: Issues, Challenges, and Opportunities."

Also of note is the establishment of a website of Colorado River materials, hosted by the Western Water Assessment: http://wwa.colorado.edu/resources/colorado_river/ (*Note*: Materials on the WWA website may be temporarily unavailable or difficult to find as the site is under re-design and reconstruction. Links will be updated as necessary.)

Two major project papers are currently in preparation. The first, entitled "Rethinking Vulnerability on the Colorado River" compares the current drought scenario to the SSD study; the second, entitled "Climate and Vulnerability in the Colorado River Basin: Incorporating Climate in River Management Policy" reviews the growing use of climate information in the development of the recently signed Record of Decision regarding Colorado River management (the EIS on which this is based includes a report on climate variability and change).

(See item II.C. for a list of publications.)

B. Summary of findings, including their potential or actual implications for efforts to develop applications, methods, and science-based decision support capacity/systems and to foster sustainable resource management and vulnerability reduction. *(Limit to two pages)*

The comparison of the SSD impacts and the actual impacts associated with the current drought strongly suggest that vulnerability has changed in important ways since the SSD study, just over a decade ago. Of particular salience is the SSD modeling result which suggested that severe drought was primarily a problem for Upper Basin users. In the SSD analysis, Lake Powell (serving the Upper Basin) dropped immediately and sharply as the drought unfolded, while Lake Mead (serving the Lower Basin) remained stable until Lake Powell was emptied. However in the current drought, both reservoirs have dropped at roughly the same rate, and the first users in the basin to face curtailments have been in the Lower Basin. This change in how drought

impacts are distributed has had tremendous political consequences, and has colored the multi-state negotiations over the past 5 years.

A major reason for the changed vulnerability of Lake Mead reservoir storage to severe drought is the increase in Lower Basin water demands. Between the early 1990s and early 2000s, provisional data from the US Bureau of Reclamation suggest that Lower Basin consumptive uses (defined here as the sum of deliveries from the mainstem to Arizona, California, and Nevada, and treaty-required deliveries to Mexico) grew by approximately 1 MAF (million acre-feet)/year (from 8.7 to 9.7 MAF/year), sufficient to pass the threshold that determines whether or not Lake Mead is stable or declining. (*Note*: Since 2004, the drought has prompted several management innovations that appear to have at least temporarily rebalanced the regional water budget.) Part of this increased consumption is explained by the completion of the Central Arizona Project (CAP), which allows Arizona to use its Colorado River entitlement to offset groundwater depletions. The project was completed just after SSD modeling was completed, and very quickly was put into full operation. Mainstem deliveries to CAP averaged 1.5 MAF/year from 2000 to 2004, which is roughly 3 times higher than the CAP demand projections used in the SSD study (derived from assumptions in the 1991 Annual Operating Plan and economic modeling that assumed CAP water would be prohibitively expensive for many users). This change in the pull of water from Lake Mead, more than any other single item, explains why the SSD and actual drought traces for Lake Mead differ so significantly.

This finding is just the latest in a decades-long string of research findings showing that vulnerability to drought is not merely a climatic or hydrological phenomena, but is largely a social construct deriving from laws, policies, customs, and other human actions. While SSD researchers were acutely aware of this familiar lesson from hazard studies, this retrospective analysis of the SSD study is a reminder of the challenge (and necessity) of accurately predicting/modeling the human component of water systems as part of climate variability/change scenario research.

The analysis also suggests that vulnerability in the Upper Basin is also more complicated than drought; climate change is likely the more serious threat. Most climate models suggest future declines in Colorado River flows, as described in Appendix U of the recent Environmental Impact Statement. A modest decline of 10 percent by late in the century—a value consistent with leading research—would mean a roughly 1.5 MAF/year reduction in average annual supplies. Under many legal interpretations, this full amount, as a practical matter, would come out of the Upper Basin apportionment. Ironically, the Upper Basin already "lost" roughly this amount last century as estimates of the mean flow of the river were reduced. This familiar story involves the error of compact negotiators in the 1920s that unwittingly used the hydrology from an exceedingly wet period to over-allocate the river. Due to this error, the Upper Basin for many years has reluctantly assumed that their reliable annual share of the river may be closer to 6 MAF than the promised 7.5 MAF. Should this drop further, as in this 10 percent reduction scenario to 4.5 MAF/year, then shortages can quickly go from theoretical to real, as Upper Basin consumption (from 1996 to 2000) averaged 4.4 MAF/year (accounting for evaporation losses). Consider the case of Colorado. Revising the "practical" Upper Basin apportionment from 7.5 MAF to 6.0 MAF drops the state's annual share from 3.9 MAF to 3.1 MAF; decreasing from 6.0

MAF to 4.5 MAF would drop this value further to 2.3 MAF—the state's current level of consumption.

Certainly this climate change scenario would not play out without legal and political wrangling and a search for management/engineering solutions, but the central message is unchanged: droughts are a real concern (especially when layered on top of climate change), but they are not the full story.

Looking back, it is fair to conclude that the SSD project was a major step forward in thinking about drought on the Colorado River. But to the extent that the study was intended to illuminate water supply vulnerability on the system, the crisis selected (i.e., severe, sustained drought) was probably too one-dimensional and featured too remote an estimated return interval to stimulate meaningful reform. Ironically, these lessons have only become obvious given our recent experience with real drought.

C. List of any reports, papers, publications or presentations arising from this project; please send any reprints of journal articles as they appear in the literature. Indicate whether a paper is formally reviewed and published. *(No text limit)*

In Production or in Press

Kenney, D., A. Ray, B. Harding, R. Pulwarty, and B. Udall. (In Production). *Rethinking Vulnerability on the Colorado River*. Likely for submission to Water Resources Impact.

Ray, A.J., D.S. Kenney, and R. Pulwarty. (In Production). "Climate and Vulnerability in the Colorado River Basin: Incorporating Climate in River Management Policy."

Kenney, D.S. (In Press). "*Hard Times on the Colorado River: A Looming Crisis*? IN: The Politics of Water Scarcity: A Survey, by Julie Trottier and Vincent Mioc (editors). Routledge Publishers.

Kenney, D.S. (In Press). "*Colorado River Basin, US*" IN: River Basin Development in Perspective, F. Molle and P. Wester (editors). CAB International: Wallingford England.

Already Published Materials

Pulwarty, R.S., and D. Kenney. 2007. "Drought-related thresholds and response curves on the Colorado River." Heinz Center.

Woodhouse, C.A., S.T. Gray, and D.M. Meko, 2006. *Updated streamflow reconstructions for the Upper Colorado River basin*. Water Resources Research, 42, W05415. doi:10.1029/2005WR004455.

Woodhouse, C.A. and J.J. Lukas, 2006. *Drought, tree rings, and water resource management*. Canadian Water Resources Journal 31, 297-310.

Presentations (associated in whole or part with this project):

Kenney, D.S. "Statutory and Institutional Challenges to Climate Change Adaptation." New Mexico Convening of Carpe Diem: Western Water and Climate Change. Albuquerque, NM; May 29, 2008.

Kenney, D.S. "Climate and Management of the Colorado River: What Does the SSD Study Tell Us About Scenario Analysis?" Annual conference of the American Geophysical Union; San Francisco, CA; December 11, 2007.

Kenney, D.S. "Climate Change and Water Resources: Trends, Projections, and Implications for the Western USA." 64th Annual Conference of the National Congress of American Indians. Denver, Colorado; November 13, 2007.

Woodhouse, C.A., 2007 Variable Precipitation and Drought in the Southwest through Time. Liquid Assets: Using Water in the Arid Southwest, Santa Fe, NM, November 3, 2007

Woodhouse, C.A. 2007. Paleoclimatology, Tree Rings, and the Upper Rio Grande. Presentation at Bernalillo County Extension, Abuquerque, November 2, 2007.

Kenney, D.S. "Collaboration and Restoration of the Colorado River Delta." "Collaboration and the Colorado River" conference; Boyd School of Law, University of Nevada, Las Vegas; October 12, 2007.

Woodhouse, C.A. 2007. Tree Rings and the Colorado River: Lessons from the Past, Southwest Hydrology and Arizona Hydrological Society 2007 Regional Water Symposium, Tucson, August 30-31, 2007.

Ray, A.J., and D. Kenney. AMS Second Symposium on Policy and Socio-economic Research. "Critical challenges in incorporating climate into management of the Colorado River" (January 18, 2007

D. Discussion of any significant deviations from proposed workplan (e.g., shift in priorities following consultation with program manager, delayed fieldwork due to late arrival of funds, obstacles encountered during the course of the project that have impacted outcome delivery). *(Limit to one paragraph)*

As noted elsewhere, the scope and duration of the project has increased significantly as continued drought makes this work increasingly timely and important, and as the "playing field" of management and policy innovations shifts at a pace far surpassing anything in the past 5 decades. The best evidence is the recently completed EIS process, which featured alternatives

derived in part from reforms proposed in the SSD study (namely, reverse equalization and interstate marketing), and the federal government's first serious attempt to integrate sophisticated climate scenarios into long-range planning efforts. Between the release of the draft EIS (spring 2007) and completion of the final EIS (late in 2007), Reclamation convened a study from the Climate Technical Work Group (published as Appendix U of the FEIS). The origination of the group and the commitment to pursue climate scenarios can be created to many people associated with the Bureau of Reclamation and the Western Water Assessment, but also individuals associated with the original SSD study (e.g., Ben Harding) and our current review of that study (e.g., Connie Woodhouse, Brad Udall). In order to take advantage of these opportunities, the duration of the project was extended to summer 2008. In-project budget allocations were modified to reflect the new timeline, but more importantly, in response to personnel changes. One project contributor (James Saunders) left the project soon after the initial proposal was submitted, another contributor (Connie Woodhouse) relocated to the University of Arizona, one PI (Roger Pulwarty) became the director of NIDIS, and two individuals (Brad Udall, Ben Harding) not listed on the project proposal became important project contributors. The willingness of NOAA to allow modifications in timing, budget and personnel has contributed significantly to the project's success.

E. Where appropriate, describe the climate information products and forecasts considered in your project (both NOAA and non-NOAA); identify any specific feedback on the NOAA products that might be helpful for improvement.

The climate products featured in the original SSD study were tree-ring reconstructions of Colorado River flow, based largely on the landmark work of Stockton and Jacoby (1976). In recent years, these reconstructions have been significantly expanded, updated and refined, largely by the efforts of project participant Connie Woodhouse. As noted above (in items II.A. and II.C.), several new dendrochronology studies, papers and workshops have been produced to augment this earlier work. The challenge in translating this field of climate science into information, data and scenarios that can be used in management is addressed in the tree-ring workshops, but also is a central focus of our collaborators in the Western Water Assessment working in conjunction with the Bureau of Reclamation. Recommendations for better using both paleo, historic (measured), and future climate projections as part of planning can be found in the report of the Climate Technical Work Group (published as Appendix U of the FEIS and entitled "Review of Science and Methods for Incorporating Climate Change Information into Reclamation's Colorado River Basin Planning Studies.")

III. GRAPHICS: PLEASE INCLUDE THE FOLLOWING GRAPHICS AS ATTACHMENTS TO YOUR REPORT

A. One Power point slide depicting the overall project framework/approach/results to date

B. If appropriate, additional graphic(s) or presentation(s) depicting any key research results thus far

C. Photographs (if easy to obtain) from fieldwork to depict study information (if applicable).

IV. WEBSITE ADDRESS FOR FURTHER INFORMATION (IF APPLICABLE)

The project posts materials on web pages maintained by the Western Water Assessment, namely:
http://wwa.colorado.edu/resources/colorado_river/
http://wwa.colorado.edu/resources/paleo/lees/

V. ADDITIONAL RELEVANT INFORMATION NOT COVERED UNDER THE ABOVE CATEGORIES.